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SCIENCE

A Weekly Journal devoted to the Advancement of Science, publishing the official notices and proceedings of the American Association for the Advancement of Science, edited by J. McKeen Cattell and published every Friday by

THE SCIENCE PRESS

11 Liberty St., Utica, N. Y. Garrison, N. Y.
New York City: Grand Central Terminal

Annual Subscription, \$6.00 Single Copies, 15 Cts.

Entered as second-class matter January 21, 1922, at the Post Office at Utica, N. Y., Under the Act of March 3, 1879.

VOL. LVI OCTOBER 6, 1922 No. 1449

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THE ORGANIZATION OF RESEARCH¹

THE principles of science are to-day widely spread; systematic scientific training has found an honorable place in the schools and in the colleges; above all, there is the realization that much of human progress is based on scientific inquiry, and at last this is fostered and, in part, financed as a definite unit of national educational policy. Public funds are devoted to provide facilities for those who are competent to pursue scientific investigations, and in this way the state, acting through the Department of Scientific and Industrial Research, has assumed the double responsibility of providing for the advancement of knowledge and for the application of scientific methods to industry. Scientific workers have been given the opportunities they desired, and it remains for us to justify all that has been done. We have to-day glanced briefly at the painful toil and long years of preparation; now it falls to us to sow the first crop and reap the first harvest.

Thanks to the wisdom and foresight of others, it has been possible to frame the government policy in the light of the experience gained with pre-existing research organizations. The pioneer scheme of the kind is that administered by the commissioners of the 1851 Exhibition, who since 1890 have awarded research scholarships to selected graduates. When in 1901 Mr. Carnegie's benefaction was applied to the Scottish universities the trustees wisely determined to devote part of the revenues to the provision of research awards which take the form of scholarships, fellowships and research lectureships. These have proved an immense boon to Scottish graduates, and the success of the venture is sufficiently testified by

¹ From the address of the president of Section B—Chemistry, British Association for the Advancement of Science, Hull, September 7, 1922.

the fact that the government research scheme was largely modeled on that of the Carnegie Trust.

In each of these organizations chemistry bulks largely, and the future of our subject is intimately connected with their success or failure. The issue lies largely in our hands. We must not forget that we are only at the beginning of a great movement, and that fresh duties now devolve upon us. It was my privilege for some years to direct the work of a chemistry institute, where research was organized on lines which the operation of the government scheme will make general. If, from the very nature of things, my experience can not be lengthy it is at least intimate, and I may perhaps be allowed to lay before you my impressions of the problems we have to face.

Two main objectives lie before us: the expansion of useful learning and the diffusion of research experience among a selected class. This class in itself will form a new unit in the scientific community, and from it will emerge the "exceptional man" to whom, quoting Sir James Dewar, "we owe our reputation and no small part of our prosperity." When these words were uttered in 1902 it was a true saying that "for such men we have to wait upon the will of Heaven." It is still true, but there is no longer the same risk that the exceptional man will fall by the way through lack of means. Many types of the exceptional man will be forthcoming, and you must not imagine that I am regarding him merely as one who will occupy a university chair. He will be found more frequently in industry, where his function will be to hand on the ideas inspired by his genius to the ordinary investigator.

I have no intention of wearying you by elaborating my views on the training required to produce these different types. My task is greatly simplified if you will agree that the first step must be systematic experience in pure and disinterested research, without any reference to the more complicated problems of applied science. This is necessary, for if our technical research is to progress on sound lines the foundations must be truly laid. I have no doubt as to the prosperity of scientific industries in this country so long as we avoid hasty

and premature specialization in those who control them. We may take it that in the future the great majority of expert chemists will pass through a stage in which they make their first acquaintance with the methods of research under supervision and guidance. The movement is already in progress. The government grants are awarded generously and widely. The conditions attached are moderate and reasonable, and there is a rush to chemical research in our colleges. Here, then, I issue my first note of warning, and it is to the professors. It is an easy matter to nominate a research student; a research laboratory comfortably filled with workers is an inspiring sight, but there are few more harassing duties than those which involve the direction of young research chemists. No matter how great their enthusiasm and abilities, these pupils have to be trained, guided, inspired, and this help can come only from the man of mature years and experience. I am well aware that scorn has been poured on the idea that research requires training. No doubt the word is an expression of intellectual freedom, but I have seen too many good investigators spoiled and discouraged through lack of this help to hold any other opinion than that training is necessary. I remember, too, years when I wandered more or less aimlessly down the by-paths of pointless inquiries, and I then learned to realize the necessity of economizing the time and effort of others.

The duties of such a supervisor can not be light. He must possess versatility; for although a "research school" will doubtless preserve one particular type of problem as its main feature, there must be a sufficient variety of topics if narrow specialization is to be avoided. Remember, also, that there can be no formal course of instruction suitable for groups of students, no common course applicable to all pupils and all inquiries. Individual attention is the first necessity, and the educative value of early researches is largely derived from the daily consultations at the laboratory bench or in the library. The responsibility of becoming a research supervisor is great, and, even with the best of good will, many find it difficult to enter sympathetically into the

mental position of the beginner. An unexpected result is obtained, an analysis fails to agree, and the supervisor, out of his long experience, can explain the anomaly at once, and generally does so. If the pupil is to derive any real benefit from his difficulties, his adviser must for the moment place himself in the position of one equally puzzled, and must lead his collaborator to sum up the evidence and arrive at the correct conclusion for himself. The policy thus outlined is, I believe, sound, but it makes severe demands on patience, sympathy, and, above all, time.

Research supervision, if conscientiously given, involves the complete absorption of the director's energy and leisure. There is a rich reward in seeing pupils develop as independent thinkers and workers, but the supervisor has to pay the price of seeing his own research output fade away. He will have more conjoint papers, but fewer individual publications, and limitations will be placed on the nature of his work by the restricted technique of his pupils.

I have defined a high standard, almost an ideal, but there is, of course; the easy alternative to use the technical skill of the graduate to carry out the more laborious and mechanical parts of one's own researches, to regard these young workers as so many extra pairs of hands. I need not elaborate the outcome of such a policy.

There is another temptation, and that, in an institution of university rank, is for the professor to leave research training in the hands of his lecturers, selecting as his collaborators only those workers who have passed the apprenticeship stage. This, I am convinced, is a mistake. Nothing consolidates a research school more firmly than the feeling that all who labor in its interests are recognized by having assigned to them collaborators of real ability.

I am not yet done with the professor and his staff, for they will have other matters to attend to if research schools are to justify their existence and to do more than add to the bulk of our journals. In many cases it will be found that the most gifted of the young workers under their care lack what, for want of a better expression, is known as "general culture."

Remember, these graduates have just emerged from a period of intensive study in which chemistry and the allied sciences have absorbed most of their attention. For their own sake and in the interests of our subject, they must be protected from the criticism that a scientific education is limited in outlook and leads to a narrow specialism. The research years are plastic years, and many opportunities may be found in the course of the daily consultations "to impress upon the student that there is literature other than the records of scientific papers, and music beyond the range of student songs." I mention only two of the many things which may be added to elevate and refine the research student's life. Others will at once occur to you, but I turn to an entirely different feature of research training, for which I make a special plea: I refer to the inculcation of business-like methods. You will not accuse me, I hope, of departing from the spirit of scholarship or of descending into petty detail, but my experience has been that research students require firm handling. Emancipated as they are from the restrictions of undergraduate study, the idea seems to prevail that these workers ought to be excused the rules which usually govern a teaching laboratory, and may therefore work in any manner they choose. It requires, in fact, the force of a personal example to demonstrate to them that research work can be carried out with all the neatness and care demanded by quantitative analysis. Again, in the exercise of their new freedom young collaborators are inclined to neglect recording their results in a manner which secures a permanent record and is of use to the senior collaborator. As a rule, the compilation of results for publication is not done by the experimenter, and a somewhat elaborate system of records has to be devised. It should be possible, twenty years after the work has been done, to quote the reasons which led to the initiation of each experiment, and to trace the source and history of each specimen analyzed, or upon which standard physical constants have been determined. I need not enter into detail in this connection beyond stating that, although a system which secures these objects has for many years been adopted in St. Andrews, con-

stant effort is required to maintain the standard.

One of the greatest anxieties of the research supervisor is, however, the avoidance of extravagance and waste. The student is sometimes inclined to assume a lordly attitude and to regard such matters as the systematic recovery of solvents as beneath his notice. My view is that, as a matter of discipline as much as in the interests of economy, extravagant working should not be tolerated. There is naturally an economic limit where the time spent in such economies exceeds in value the materials saved, and a correct balance must be adjusted. It is often instructive to lay before a research worker an estimate of the cost of an investigation in which these factors of time and material are taken into account. As a general rule it will be found that the saving of material is of greater moment than the loss of time. The point may not be vitally important in the academic laboratory, but in the factory, to which most of these workers eventually migrate, they will soon have the lesson thrust upon them that their time and salary bear a small proportion to costs of production.

You will see I have changed my warning from the professor to the student. A student generation is short. In a few years, when almost as a matter of course the best of young chemists will qualify for the doctor of philosophy degree, it will be forgotten that these facilities have come to us, not as a right, but as a privilege. Those who reap the advantages of these privileges must prove that the efforts made on their behalf have been worth while.

Looking at the position broadly, if one may criticize the research schemes of to-day, it is in the sense that the main bulk of support is afforded to the research apprentice, and the situation has become infinitely harder for the supervisor in that new and onerous tasks are imposed upon him. To expect him to undertake his normal duties and, as a voluntary act, the additional burden of research training is to force him into the devastation of late hours and overwork. The question is at once raised—Are we using our mature research material to the best advantage, and is our policy sufficiently focussed on the requirements of the

experienced investigator? I think it will generally be agreed that members of the professor or lecturer class who join in the movement must be relieved in great measure of teaching and administrative work. I am decidedly of the opinion that the research supervisor must be a teacher, and must mingle freely with undergraduates, so as to recognize at the earliest possible stage the potential investigators of the future and guide their studies. To meet this necessity universities and colleges must realize that their curriculum has been extended and that staffs must be enlarged accordingly. There could then be definite periods of freedom from official duties for those who undertake research training as an added task. Opportunities must also be given to these "exceptional men" to travel occasionally to other centers and refresh themselves in the company of kindred workers. It is evident that our universities are called upon to share the financial burden involved in a national research scheme to a much greater extent than possibly they know.

I may perhaps summarize some of the conclusions reached in thinking over these questions. The first and most important is that in each institution there should be a board or standing committee entrusted with the supervision of research. The functions of such a body would be widely varied and would include:

1. The allocation of money voted specifically from university or college funds for research expenses.
2. The power to recommend additions to the teaching staff in departments actively engaged in research.
3. The recommendation of promotions on the basis of research achievement.
4. The supervision of regulations governing higher degrees.

Among the more specific problems which confront this board are the following:

1. The creation of research libraries where reference works can be consulted immediately.
2. The provision of publication grants, so that where no periodical literature is available the work will not remain buried or obscure.
3. The allocation of traveling grants to en-

able workers to visit libraries, to inspect manufacturing processes, and to attend the meetings of scientific societies.

There is one thing which a research board should avoid. It is, I am convinced, a mistake for a governing body to call for an annual list of publications from research laboratories. Nothing could be more injurious to the true atmosphere of research than the feeling of pressure that papers must be published or the department will be discredited.

What I have said so far may seem largely a recital of new difficulties, but they are not insurmountable, and to overcome them adds a zest to life. It would have taken too long to go more fully into details, and I have tried to avoid making my address a research syllabus, merely giving in general terms the impressions gained during the twenty years in which the St. Andrews Research Laboratories have been in existence.

I have confined myself to the first stage in the research development of the chemist. His future path may lead him either to the factory or to the lecture-room, and in the end the exceptional man will be found in the director's laboratory or in the professor's chair. However difficult these roads may prove, I feel that with the financial aid now available, supported by the self-sacrificing labors of those who devote themselves to furthering this work, he has the opportunity to reach the goal. It is the beginning of a new scientific age, and we may look forward confidently to the time when there will be no lack of trained scientific intellects to lead our policy and direct our efforts in all that concerns the welfare of the country.

J. C. IRVINE

THE UNITED STATES FUNDAMENTAL STANDARDS OF LENGTH AND MASS

THE recently published volume containing the testimony submitted to the Senate Committee on Manufactures, in favor of and against the passage of Senate Bill 2267 "To fix the Metric System of Weights and Measures as the Single Standard of Weights and Measures for Certain Uses," contains a mass of information and misinformation of great interest to students of metrology.

The opponents of the metric system were very active in marshalling their full strength at the numerous "hearings" before the subcommittee, about half of the volume being devoted to the evidence which they furnished, either in writing or in the form of personal testimony.

These are the pages which the well informed reader will certainly find most interesting, because of the remarkably illogical arguments introduced, the total disregard of historic facts and the apparently complete ignorance of the fundamental principles of the science of metrology.

This is especially true of the testimony of Mr. C. C. Stutz who, born in Italy of Swiss parents, seems to have been thought particularly fit to be chosen as the representative of the opposition, being the secretary of the American Institute of Weights and Measures, an organization created, as the secretary declares, "for the purpose of defending the existing American system of weights and measures against pro-metric propaganda,"—and also for the improvement of the same, though evidence of the latter objective seems yet to be forthcoming.

Mr. Stutz is especially agitated because, as he says, "the impression has been spread throughout the United States and abroad that the meter and not the yard is the legal standard here"—discussing that question at great length on pages 173-4-5-6 and again pages 318-19-20 of the Report of the Hearings. He creates an imaginary American "inch," contending that it is exactly the same as the English inch and hence the English yard and the American yard are identical.

In reference to this particular part of Mr. Stutz's voluminous testimony the statement of a few facts that are well known to most metrologists may be useful.

The constitution of the United States declares that Congress shall have power "to fix the standard of weights and measures," but Congress has never exercised that power, except in a few isolated instances, the most important being the adoption of the decimal system for the coinage and currency of the United States in 1785—with the subsequent adoption in 1828 of a material standard "troy